SUMMARY PROGRESS REPORT

to the

National Aeronautics and Space Administration

Research Grant	:	SC-NsG-215-62
Title	:	Electrophysiological Correlates of Vigilance and Learning
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I. Perhaps it would be useful to start this Progress Report by outlining the areas of behavioral relevance of the work conducted this year under NASA grant NsG 215-62 concerned with the "Electrophysiological Correlates of Vigilance and Learning." These are:

1. Prediction, from EEG parameters, of fluctuation of vigilance levels in prolonged tasks requiring monitoring of aperiodic environmental signals;
2. The effects of warning signals upon speed of performance in reaction to such signals;
3. The effects of extraneous signals upon performance in such situations;
4. The relationship between the array of environmental signals with which the person has to deal and his speed of response to selected critical signals;
5. The temporal limits for efficient processing of signals: investigation of the effects of different intervals between successive stimuli in terms of (a) the behavioral efficiency in dealing with critical signals when extraneous signals either precede or follow them, (b) the ability to perceive each event as separate in time;
6. Effect of the attitude of the observer toward signals: (a) when the subject is set to focus attention on one particular signal rather than another presented in the same sensory modality; (b) whether or not the subject attempts to synchronize his response with a signal (anticipation).

II. The electrophysiological data fall into three general classes:

1. Spontaneous background activity;
2. Signal-induced activity that is not necessarily time-locked to

the signal;

3. Signal-induced activity which is time-locked to the stimulus, i.e. evoked potentials.

All of the work to be discussed in this report, then, can be considered as bearing on one or more of the behavioral questions outlined in the first section and utilizing one or more of the electrophysiological measures outlined in the second section. A number of experiments were designed to investigate some of the neurophysiological mechanisms involved in information processing by the human observer.

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1. Predictions of fluctuations of vigilance

In 1966, a paper entitled "EEG frequency and reaction time - A sequential analysis" was published in Neuropsychologia (Vol. 4: 41-48) which summed up our earlier work on EEG background predictors of performance. Also, a paper relating evoked potentials to reaction time behavior appears in the journal, EEG and Clinical Neurophysiology, Vol. 20:5: "Evoked potentials and reaction times: A study of intra-individual variability." A third paper, entitled "Some characteristics of alpha provocation," has been accepted for publication by the EEG Journal. For details of these, see our earlier report and the enclosed reprints.

As noted before, we have developed computer-based recognition techniques for the same EEG parameters, using such methods as period analysis and the mean power in segments of record just prior to presentation of critical signals. We have delayed publication of this work because we are continuing to evaluate a number of analytical methods. We are now re-running some of this data with the same programs through appropriate analog filters before automatic recognition is attempted, and wish to compare the results with digital filtering techniques.

Another series of experiments was undertaken with Dr. John S. Barlow while he was visiting our laboratory in which we investigated reaction times in relation to the phase of alpha at the time of signal delivery. There have been a number of reports in the literature dealing with the question of whether signals coming at one or another alpha phase might be associated with faster or slower response times, none of which is conclusive. We undertook some studies to answer perhaps a more basic question, namely, whether variability in performance is less when the signals are always presented at a given phase of the alpha than when they are not. The results of our experiments, dealing with brief auditory signals, lend support to the general impression from previous literature that, in fact, there is no consistent relationship between phase of alpha and speed of response which stands up across a group of unselected subjects. For some subjects, variability seems clearly reduced when the phase of alpha was constant; for other subjects, alpha phase has no significance.

2. <u>Effects of warning signals upon performance.</u>

We have found, not unexpectedly, that warning signals do increase the speed of response to a critical signal. The analysis so far has dealt only with warning signals bearing a fixed temporal relation to the critical signal over the range of 500-700 msec. Preliminary analysis of the electrophysiological correlates of such effects show that the evoked response to the critical signal is reduced when a warning signal occurs at some fixed time interval prior to it.

3,4,5. <u>The effects of extraneous signals upon performance; temporal intervals between successive stimuli.</u>

We have undertaken a major series of experiments dealing with the effects of extraneous stimuli coming at various temporal intervals after a critical signal to which the subject is set to respond as rapidly as possible. Experiments cover conditions in which a visual stimulus is the critical signal for response, and an auditory stimulus is the extraneous one, and vice versa. These experiments have been done under two conditions: (A) at unpredictable intervals, the subject is presented with the critical signal. This is followed by an extraneous stimulus in another sense modality at various delays after the first signal. The range of values used in the present experiments is from 20-120 msec. The control condition is the presentation of the critical signal alone. (B) The same sort of experimental conditions as in (A) are followed, with the exception that on some trials only the non-critical stimulus (i.e. the one to which no response is to be made) is presented. (B) is thus a choice reaction experiment. Over twenty experiments have been conducted along these models, all of which have been programmed by the LINC to assure appropriate randomization of interstimulus intervals, intertrial intervals, and also to control the required probabilities of occurrence of each of the stimulus patterns to be examined. Under both sets of experiments (A and B), a rather striking consistency of findings emerged. Reaction time was most prolonged for the single signal condition. Reaction times to the compound stimuli of critical signal followed by extraneous stimulus followed a roughly linear curve as the interval separating the two stimuli increased. The fastest reaction times occurred at minimal separations, i.e., 20 msec and 40 msec, while reaction times where the signal was followed by 100 msec and 120 msec began to approach the critical signal alone values, and for some subjects exceeded them. Another finding was that all reaction times were prolonged when the ensemble of stimuli with which the subject had to deal contained some to be ignored.

Comparison of the results from experiments A and B indicates that when the subject is given an array of signals, each of which is a signal to respond, his performance is faster by 40 msec than when he is given an array of signals, some of which he has to ignore (withold response). Further there is the intriguing implication that the prolongation of central processing time by requiring a decision, alters the temporal function relating reaction times to inter-stimulus intervals. In B (with a required choice of whether to respond) the extraneous stimulus has its effects over a longer range of inter-stimulus intervals than in experiment A.

Rather striking parallels were found between these behavioral curves and the evoked potential patterns measured for the same conditions. The compound evoked potentials showed great enhancement over that range of inter-stimulus intervals which showed behavioral facilitation (20-80 msec). Eighty msec seemed to be a rather striking shut-off point for the enhancement effect. Thus, the evoked potential to light when followed by a click at 100 or 120 msec did not look very much different than the evoked potential to the light when it was not followed by another signal.

Quantitative analysis of both behavior and evoked potential data from these experiments has been in part completed. One method developed is deriving the integral of the voltage in the evoked potential (over the first 256 msec from stimulus onset). Using these scores, we calculated the average rank correlation coefficient between evoked potentials and reaction times, as a function of interstimulus intervals. Analysis of several EEG channels have been completed at this writing: the average rho values observed range from .64 - .73, and all are well beyond chance (p = .01).

In addition, we have computed cross-correlation matrices of the set of evoked potentials from a given experiment. Both cross-correlation with no time offset, and one entire cross-correlation function across a range of temporal displacements of one wave from another have been done. We have not had enough time to examine more than a few channels of data as yet. However, cross-correlation methods appear useful as a way to quantify and objectively group compound evoked potentials which vary with regard to inter-stimulus interval. Thus, one might have electrocortical measures for defining temporal intervals which are associated with facilitation and inhibition. Factor analysis of these matrices is planned.

We are currently pursuing a number of issues raised by these data, among them whether or not the enhancement that we see represents a true interaction term. Is the response to the compound stimulus more than a simple addition of the response to the two separate stimuli comprising the potential? We have begun to investigate, using the data available from this set of experiments, the properties of compound evoked potentials to see how well the compound potential is linearly predictable from the single potentials with appropriate displacements in time.

5b. Two different approaches have been employed to assess the limits of the ability of persons to perceive signals as discrete separable events in time. One set of data deals with accuracy of judgments and decision time in situations where signals from two different sense modalities are presented. Our preliminary findings are that visual signals followed by auditory signals are likely to be perceived as simultaneous 75% of the time (or more) when the inter-signal interval is 80 msec or less, 50% of the time at 100 msec separations, and 25% of the time at 100 msec separations. Decision time is most prolonged at 120 msec separations; from the nature of our particular experiments, this indicates we are near a marginal region for this effect. These data are closely correlated with the evoked potential patterns obtained; when simultaneity judgments are likely (i.e., at intervals <u>less</u> than 100 ms) the compound evoked potentials show a merging of the two signals in at least one biphasic wave (negative-positive complex with latencies to first inflection point at approximately 100 ms). Further data collection is planned to establish the limits of temporal resolution.

A second series, dealing with the so-called temporal numerosity function has been started. Only pilot studies have been done, but the computer-based programs for conducting the experiments and retrieving the data are now ready, and await only available time of the investigators for a more definitive experimental series. The basic model is the presentation of trains of stimuli (e.g. a train of flashes or a train of clicks), the inter-stimulus interval being fixed over a given run but varied in different runs. The object of this series of studies is to investigate the perceptual limits (in terms of temporal separation) for resolution of each stimulus as discrete, in conjunction with the electrophysiological correlates of the functions assessed.

6. <u>Effect of instructions to the observer in dealing with complex stimuli:</u>

a. <u>Intramodality selective attention and evoked responses.</u> (This work was carried on by Dr. Emanuel Donchin and was presented at the Third Annual Symposium on Temporal Factors in Vision in Rochester, New York in June

1966.) Subjects were presented with a visual stimulus that varied independently on two different stimulus dimensions. The subject was instructed alternately to respond to variations in one of the dimensions while ignoring the other. Evoked responses could be obtained for each of the dimensions. The data indicate an enhancement of the response to the attended-to dimension. These data refute Horn's suggestion that visual search per se attenuates evoked responses; they are also inconsistent with the suggestion of a peripheral blocking mechanism as the sole responsible factor for selective attention.

b. A paper entitled "Some observations on evoked responses in relation to temporal conditioning to paired stimuli in man" was recently published in Quarterly Progress Report No. 78, MIT Research Laboratory of Electronics, the result of collaborative experiments conducted in our laboratory with Dr. John S. Barlow. The investigation focused upon possible intrinsic timing mechanisms of the brain. Evidence for conditioned electrocortical activity was evaluated.

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III. <u>Other work conducted in the period July 1, 1965 - June 30, 1966.</u>

Another series of experiments was undertaken to study the possibly related questions of motor potentials (potentials related to the occurrence of motor responses such as switch-depression) and cross-hemispheric differences in electrocortical activity. These were done in collaboration with Dr. Emanuel Donchin and Dr. Herman Buschke.

Briefly, subjects were instructed to respond to a click with their right hand and to a flash with their left hand, or vice versa. Clicks and flashes were either presented alternately or mixed in a fixed proportion in a random order. The average evoked response recorded between electrodes C3-C4 indicated a different response in each hemisphere to each stimulus. The responses to the clicks were of an opposite polarity to the responses to the flash. The polarities did not depend on the hand used for each stimulus. There is a wide inter-subject variability in the form of the difference wave.

We are currently examining the antecedent potentials locked in time to the motor response; this requires backward digitizing and averaging.

2. We have developed a program to identify the phase of alpha at the time of stimulus delivery <u>post hoc</u>, that is, after an experiment is concluded in which signals were randomly presented. When time and staff permit, we wish to use this program to further evaluate the question of the relationship between alpha phase and reaction times.

3. <u>Relationship between evoked response amplitude and alpha blocking</u>. A LINC program was developed to recognize alpha blocking responses and to determine their duration and latency, using the approach suggested by Belmont Farley. Subjects were presented with flashes of light and the trials were classified according to the duration and latency of the blocking response. Average evoked responses were obtained for the various categories. In general, the amplitude of the evoked response was larger on those trials in which the alpha was blocked.

4. Multivariate analyses of evoked response data.

Discriminant analysis techniques were applied to data from a variety of evoked potential experiments. Results confirmed that it is possible to classify correctly a large percentage of the single trial records in an evoked response experiment as to the eliciting stimuli. None of the analyses was adequately completed due to a lack of proper LINC to 7094 communication.

4. Development of computer programs.

In addition to those referred to briefly above, we have further increased our library of analytical programs for the LINC computer (voltage integration and mean square values over any desired epoch of EEG data cross-correlation matrices for a set of evoked potentials) and for rapid retrieval and evaluation of behavioral data.

The general theme of these experiments is the relationship obtaining between electrical activity of brain and specific kinds of behavior. The behaviors are those of monitoring informationally valuable signals in a monotonous environment such as might be encountered in space flight.

The experimental design is one which could be implemented in actual space flight conditions. To be gained is specific knowledge of how the human nervous system optimally handles information and of the optimal way in which to present information to a human observer in space flight.